

Surf Zone Robotics

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LONG TERM GOAL

As part of the Office of Naval Research's Very Shallow Water/Surf Zone (VSW/SZ) Program, this effort seeks to demonstrate exploration and mapping of surf zone minefields using autonomous bottom crawling robots (crawlers). The ultimate goal is to transition a robotic reconnaissance capability to the fleet that will eliminate the need to send divers into the surf zone. The enabling capabilities required for robotic reconnaissance will also allow robots to reacquire and mark or neutralize targets.

OBJECTIVES

The objectives are to develop and demonstrate the following key capabilities:

- The ability to move and position in strong currents and over rough, varied underwater terrain.
- The ability to systematically search a field with single or multiple vehicles and achieve a known and optimized coverage for the mission over the area of interest (navigation/positioning).
- The ability to detect mine-like targets and discriminate threat objects from common clutter.
- The ability to transmit commands and data through-water between a remote human operator and the robots and between the robots and to tolerate limited channel availability.
- The ability to control vehicles in a supervised autonomous manner and monitor mission progress.

APPROACH

The general approach is to develop navigation, control, and sensing technologies toward performing a series of capability demonstrations. The major demonstrations include:

- Land field search and area coverage (fall 2000).
- Target detection, imaging, and reporting (summer 2001).
- Single/multi-vehicle in-water minefield exploration and reconnaissance (summer 2002).

A dedicated effort is developing control techniques and command scripting to enable in the field adjustment of behaviors that support field searching and target sensing¹. The scripting system is a forth-

like interpreted language that allows the vehicle's program to be changed remotely on the fly. This scripting system will be used for each of the planned demonstrations.

During FY00 a Position Estimator (PE) algorithm was developed to facilitate navigation. The PE fuses onboard instruments with an external baseline system to provide robust position-motion estimate despite the intermittent nature expected of an acoustic baseline system in the surf zone. We have found that with the vehicle in motion, signals may drop out or produce anomalous data points even when using a Global Positioning System (GPS) baseline in an open field. The fused system allows the vehicle to navigate by dead reckoning when such dropouts or anomalies occur.

Development of the PE has progressed by recording instrument and baseline data on land while remotely steering the crawler between known waypoints². The instruments currently include a compass, yaw gyro, odometers, and a GPS baseline system. The GPS system acts as a stand-in for an underwater acoustic or magnetic baseline when operating on land. GPS aids system development by providing a reference or truth track. We post-process the recorded data files through the PE algorithm and calculate the error of the position estimate against the reference track file for each run. The navigation instrument models and the algorithms are adjusted to minimize this error. An acoustic baseline was developed this year for in-water use.

Sensors are being developed jointly by CSS under 6.2 funding under the Surf Zone Reconnaissance Project³ and by Foster-Miller, Inc. under 6.3 program funds. The general approach is to develop promising contact, magnetic, and optical sensor concepts and to select a suite of sensors that will exploit useful target features at close range (<4m)⁴. We have collected sensors signatures for analysis using the sensor development Lemming in Figure 1, and we will continue to use the vehicle to develop the behaviors that support using the sensors.

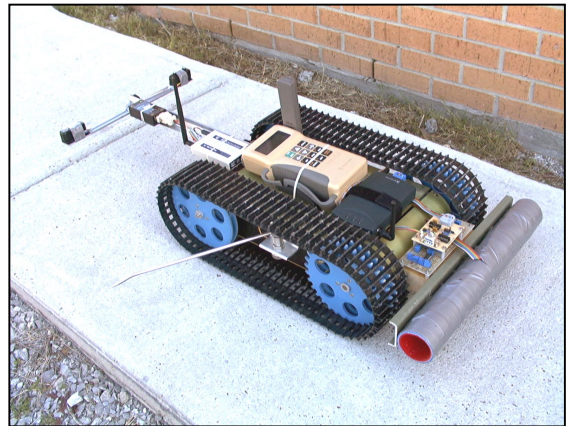


Figure 1. Sensor development Lemming

We plan to select two sensor suites for the FY01 demonstration, one supporting exhaustive mapping using multiple crawlers and another supporting lane exploration using a single crawler. Selection will be based on sensor maturity, however, continued development of other promising sensors will continue. Additional supporting efforts include incorporation of high ratio image compression algorithms^{5,6} and algorithms for optimal discrimination between mine-like targets and other objects likely to be encountered on the sea floor. Detection algorithms are being developed under a contract with Fast Mathematical Algorithms and Research (FMAH).

We emphasize providing an image of threat-like targets to allow a human to remotely identify the target. CSS has developed a new serial interface CMOS camera for this purpose⁷. Because of limited through-water communication bandwidth, three critical factors affect exploitation of target images. First, the number of sent images of non-threat targets must be minimized by exploiting other target features to reject non-threat targets. Second, high-ratio image compression algorithms will be required, and third, images must be pre-screened onboard for adequate quality before being transmitted.

WORK COMPLETED

The major accomplishments in FY00 include completion of the command-scripting interpreter, demonstration of the position estimator and autopilot, development of the Lemming Acoustic Navigation System (LANS) acoustic baseline system, and preparation for the search and coverage test series and demonstration scheduled for fall 2000. Foster-Miller has also made improvements to the vehicles. The following discussion will expand on these efforts.

*Sensor Developments*³. Several of the contact sensors are maturing and we are beginning to redesign several sensors for sea testing. In FY01 the program will emphasize integrating the sensor suites onto the crawlers and demonstrating detection and transmission of mine-like target images.

*Vehicle Control and Command Scripting*¹. A scripted mission at FBEH rehearsal commanded the vehicle to travel between a series of waypoints. Mission scripting is a key development because it facilitates design and optimization of search, mobility, and sensor support algorithms by allowing program changes to be made in the field without modifying hard code in the vehicles.

Position Estimator and Autopilot. The PE was successfully used to navigate the crawler in Ft. Lauderdale along a scripted path. The PE was also adapted to recognize and accept either acoustic or GPS baseline system data automatically. We plan to add accelerometers for measuring bottom roughness and estimating track slippage, which will improve dead reckoning accuracy over rough terrain and through turns.

Lemming Acoustic Navigation System. The LANS system was adapted from the Swimmer Inshore Navigation System (SINS) as an embeddable acoustic baseline system for crawler navigation⁸. The system consists of two transponders that are surveyed into the field. Any number of crawlers may operate in the field once the transponders are in place. The transponders and receivers are time synchronized prior to operation, and the receivers operate passively, calculating their position by triangulation based one-way time of flight from each transponder. A separate clock unit or a spare transponder can be used to maintain synchronization timing so that the transponders are not required to be located together with the vehicles before deployment. A radio or optical time synchronization port has been added to simplify setup.

LANS was tested in St. Andrews Bay (calm water with sand/mud bottom) and found to work very reliably even in two feet of water. In Ft. Lauderdale during the Fleet Battlelab Experiment-Hotel (FBE-H) rehearsal, we confirmed that LANS obtained valid receptions over 90 percent of the time in high Sea State 2 once the crawler was seaward of the breaking surf. This result was expected because at the LANS operating frequency the acoustic channel is highly attenuated by bubbles. The FBE-H results suggest that the crawlers can navigate the entire surf zone if they can dead reckon from seaward of the breakers



Figure 2. TAR vehicle and radio/GPS float at FBEH rehearsal prior to sea test

into the beach. The implication is that searching on tracks perpendicular to the beach would facilitate navigation. Plans are in place to manufacture several sets of LANS transponders and receiver boards for future use.

Sea Runs at FBE-H Rehearsal in Ft. Lauderdale. The CSS crawler team was asked to participate in the FBE-H rehearsal in June 2000 at Ft. Lauderdale. The goal was to have the crawler autonomously navigate a predetermined path in along the sea floor, and more generally to allow the team to get some real in-surf experience with the vehicles. In addition to preparing the control system and navigation algorithm for the on-land search and coverage tests, we had to waterproof all vehicle components, ready and test the LANS system, and build a tethered tracking float. This represented a significant effort over the work initially planned for the 2000 fiscal year. Reference 9 documents the events in detail.

CSS obtained two Tactically Adaptable Robot (TAR) vehicles from Foster-Miller in April 2000. One chassis was used as a non-water proofed test breadboard, while the other was fitted with a new watertight electronics housing containing the control computer, LANS receiver, and motor drivers. A communications float was modified to house a GPS tracking system and radio modem. The vehicle and float used in FBE-H rehearsal are shown in Figure 2 and the vehicle internal components are shown in Figure 3. The GPS system was used only to provide a reference track for comparison with the vehicle's onboard position estimate. The vehicle accepted commands and broadcast its position estimate and tracker position continuously so that a plot of estimated position versus true track (GPS track) was generated for each run. The plot of

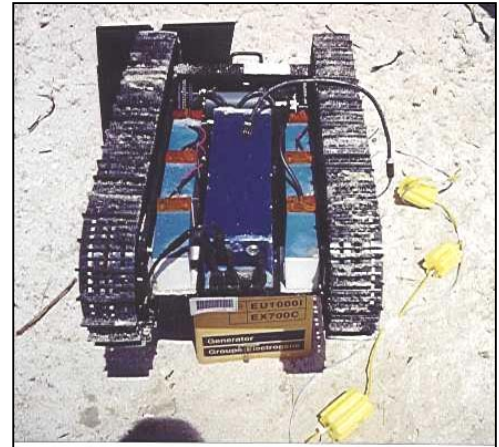


Figure 3. TAR vehicle showing batteries and electronics housing

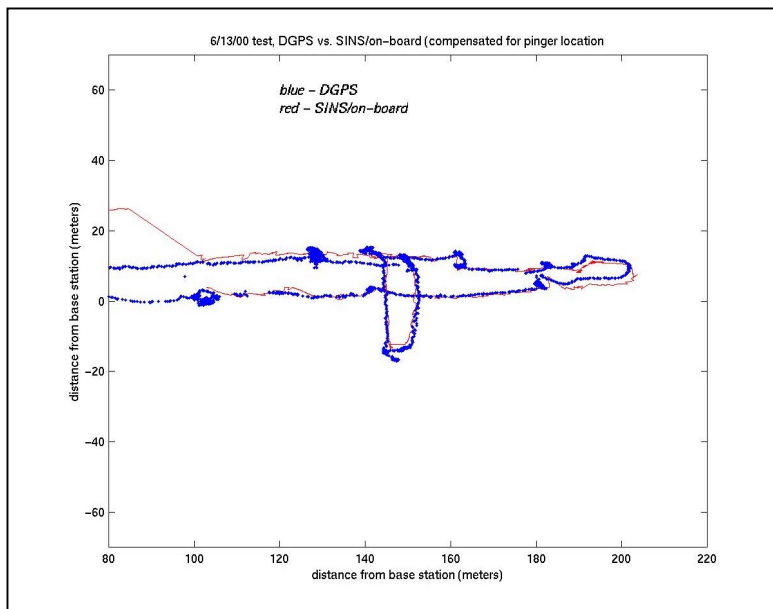


Figure 4. FBE-H rehearsal position estimator track versus float-GPS track, corrected for transponder placement error

Figure 4 shows the vehicle's position estimate against the reference GPS track.

Search and Coverage Test Series and Demonstration. The search/coverage test series and demonstration planned for summer 2000 has been delayed until fall due to delays obtaining the new vehicles for the test. The goal of the test series is to demonstrate, on land, the ability to autonomously command and navigate a group of six vehicles over a test field and to obtain thorough area coverage of the field. The test plan¹⁰ includes placing both sparse and dense object fields that represent real minefield objects and inaccessible areas such as coral outcrops. The objects will force the crawlers to exercise obstacle avoidance maneuvers as they search. This will be achieved using

mechanical bumpers that sense collisions with the field objects.

One series of tests will verify that the coverage times and percent area coverage agrees with simulation data collected by the CSS modeling and simulation team¹¹. Another series will test the ability of one crawler to explore a lane by determining the time required encountering threat objects. This will indicate the ability for a single scout vehicle to explore a minefield determine whether a threat exists, what type of threat is present.

CSS will collect vehicle motion and reference track files for every vehicle during each run. This will allow us to quantify the position estimator error. During some runs, we plan to turn off the DGPS baseline receivers intermittently to measure the accumulated positioning error while dead reckoning. Foster-Miller is preparing a camera-based video tracking system to record vehicle motion and allow visual replay of area search over the field.

RESULTS

The following results are summarized:

- We can now estimate vehicle position onboard to within 1m on land and 3m in the sea. We demonstrated positioning in Ft. Lauderdale in a high Sea State 2 over a very rough bottom.
- We can script missions for the crawler and modify the scripts on the fly.
- Development of an onboard vehicle network has begun. Networking components will reduce onboard cabling requirements, improve reliability, and simplify adapting new components.
- New vehicle developments include direct drive motors, increased search life and payload capacity, and an improved track design to resist derailments and jam related failures.
- The test field for the search and coverage test series is currently being prepared. The tests will measure area coverage rates using multiple vehicles in a realistic, scaled minefield.

IMPACT/APPLICATION

The impact of this effort will ideally be a positive response and heightened interest in crawler reconnaissance by the Navy acquisition community. If we are successful in showing the potential of the crawler to explore, map, and provide remote detection and identification of minefield objects, we should expect to generate interest in acquiring future systems. The capabilities that we intend to demonstrate are also essential to performing neutralization, surveillance, and other missions. Success of this effort will lead to a capability to efficiently explore and prosecute minefields remotely, and elimination of the need to put men into surf zone minefields.

TRANSITIONS

Transition to the 6.4 level would likely occur in the 2010 time frame based on success of planned demonstrations.

RELATED PROJECTS

A similar effort is the Basic Unexploded Ordnance Gathering System (BUGS), managed by the Naval Explosive Ordnance Disposal Technology Division (NAVEODTECHDIV). This system, now in phase two, is developing multiple robots to search for unexploded ordnance (UXO) on land and carry it to disposal areas. The BUGS concept requires the same supporting capabilities of navigation, controls, mobility, and sensing.

REFERENCES

1. M. Gavrilash, 2000. Vehicle Control System Development, Fiscal Year 2000 annual report to ONR, September.
2. Mark Connolly, 2000. Position Estimator and Locator Algorithms, internal program memo, July.
3. Charles Bernstein, 2000. Surf Zone Reconnaissance Project, Fiscal Year 2000 annual report to ONR, September.
4. Charles Bernstein, 2000. Close-Range Sensors for Unmanned Bottom Vehicles: Update, *J. SPIE Aerosense*, vol. 4039-03, March.
5. M. Caimi, G. Ritter, and M. Schmalz, 1999. HBOI/UF CUVC – Compressive Underwater Video Camera with Uplink, final report to ONR, Harbor Branch Oceanographic Institution, Inc., July.
6. J. Walker, and T. Nguyen, 2000. Wavelet Based Image Compression, Draft chapter of *CRC Handbook of Transforms and Data Compression*, June.
7. Rand Chandler, 2000. ECM (Embedded Camera Module) Data Package, Surf Zone Reconnaissance Project internal memo, August.
8. Timothy McTrusty, 2000. LANS Receiver Tech Note, internal program memo, July.
9. Charles Bernstein, 2000. FBE-H Rehearsal Exercises, internal program memo, July.
10. Charles Bernstein, 2000. Surf Zone Test and Demonstration 2000: Field Search and Coverage, internal program test plan, Coastal Systems Station, Panama City, FL 32407, May.
11. Chau Hoang, 2000. Preliminary simulation results for search and coverage test series, internal program memo, June.